

# **Assessing the Minimum Number of Synchronization Triggers Necessary for Temporal Variance Compensation in Commercial Electroencephalography (EEG) Systems**

**by Keith W. Whitaker and W. David Hairston**

**ARL-TN-0495**

**September 2012**

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## 1. Introduction

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Electroencephalography (EEG) is a procedure for measuring brain activity, as represented by voltage fluctuations measured at the scalp. This method is a focus of the U.S. Army Research Laboratory's Translational Neuroscience Branch because of its potential as a fieldable technology for measuring brain activity. Event-locked analyses of EEG data requires that brain activity data is precisely recorded in time relative to external events, or else the computed average signal may be significantly different than the actual average signal (Luck, 2005).<sup>1</sup> When using multiple devices for data acquisition, one must account for potential timing variance and drift between devices in order to ensure accurate data representation and external event logging (Luck, 2005).<sup>2</sup> For instance, uncorrected timing drift will alter the averaged brain activity in response to an event as soon as it exceeds the significant digits of time recorded by the system. A recent ARL Technical Report (Hairston, 2012)<sup>3</sup> describes this issue in detail, providing some examples of how averaged EEG signals would be impacted by varying amounts of timing drift and variance between components of a multi-unit system.

Hairston described (Hairston, 2012)<sup>4</sup> an algorithm that can be used to correct for these errors, using measurements of timing drift within various EEG systems derived from a recording session measuring over a long period of time. It would be preferable, however, to quantify system drift at the time of each experimental session when EEG is recorded, eliminating any errors introduced by day-to-day variance in the system and providing a streamlined correction procedure. If this approach is taken, data must be completed in a pragmatic and time-efficient manner in order to reduce the time commitment of the research participant before they can begin their task and keep the total session time to a minimum.

This report is a follow-on analysis of the data from Hairston (2012),<sup>5</sup> with the goal of assessing the minimum number of trigger pulses necessary to properly characterize the clock drift present in each of the EEG systems currently in use by the ARL Translational Neuroscience Branch. It covers the Emotiv EPOC,<sup>6</sup> Advanced Brain Monitoring (ABM) B-Alert X10,<sup>7</sup> Quasar<sup>8</sup> DSI helmet-based prototype, and Biosemi ActiveTwo.<sup>9</sup>

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<sup>1</sup> Luck, S.J. *An Introduction to the Event-Related Potential Technique*; MIT Press: Cambridge, Massachusetts, 2005.

<sup>2</sup> Ibid.

<sup>3</sup> Hairston, W.D. *Accounting for Timing Drift and Variability in Contemporary EEG Systems*; ARL-TR-5945; U.S. Army Research Laboratory: Aberdeen Proving Ground, MD, 2012

<sup>4</sup> Ibid.

<sup>5</sup> Ibid.

<sup>6</sup> EPOC is a trademark of Emotiv.

<sup>7</sup> B-Alert X10 is a trademark of Advanced Brain Monitoring.

<sup>8</sup> Quasar is a trademark of Quasar.

<sup>9</sup> ActiveTwo is a trademark of Biosemi.

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## 2. Methods and Results

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Specific details of data collection can be found in Hairston (2012).<sup>10</sup> Briefly, 500 pulses were sent from a PC running E-prime (Psychology Software Tools, PA) into each EEG system's data integration unit with an arbitrary interval of 1250 ms between pulses. These pulses were recorded by a separate data acquisition computer (DAQ) running the respective software provided by the manufacturer of each EEG system. We compared the recorded inter-pulse interval (IPI) against the E-prime value of 1250 ms. Prior to testing, this computer running E-prime was confirmed against a calibrated function generator to show no measurable drift relative to absolute time across the length of time used for this recording. For each EEG system, a regression equation derived the relationship between the timing error (1250 minus observed IPI) and the presentation of 500 calibration pulses. The slope of the line represents a percent drift between the IPI recorded by the DAQ and the actual IPI.

In order to better understand the relationship between the variability of the IPI for each EEG acquisition system and determination of the drift in timing error, we re-calculated the slope of the regression line for subsets of the IPI data. For each system, we initially calculated the slope of the regression line for the first 20 IPIs and iteratively recalculated the slope with the addition of the next IPI. We continued to add one more IPI at each iteration to visualize the point where the amount of change in the slope of the regression line with each IPI decreases to zero.

Emotiv's EPOC system showed the largest amount of drift and variance in timing accuracy with recorded IPI errors of hundreds of milliseconds (figure 1A).

Over the course of the calibration period (~10.5 mins), this resulted in nearly 0.5 s of error between the actual pulse event occurring and recording of the event relative to the EEG data, denoting substantial timing drift. Additionally, the high variability in the recorded IPI of the EPOC system required more than 200 pulses to estimate the timing drift (figure 1B). In comparison, Biosemi's ActiveTwo and ABM's B-Alert X10 both showed similar amounts of time drift to one another, leading to an error in the recorded IPI of tens of milliseconds for the entire period (respectively, figure 1C-F). The drift of both systems was accurately measured with 150 calibration triggers sent over the course of 3 min, evident by the asymptote in figure 1C-F. Quasar's EEG system displayed the least amount of time drift (4 milliseconds total as in figure 1G). Due to the rarity of incremental changes, this system requires a large number of calibration stimuli in order to resolve (more than 300 triggers as in figure 1H). That is, the drift in timing is low enough that the DAQ cannot accurately measure it and therefore the calibration session requires a longer length of time to accumulate enough drift to be measured. The distinctive step-wise pattern of error values in ABM, Biosemi and Quasar's EEG system is the result of the DAQ

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<sup>10</sup> Hairston, pg. 1.



rounding time measurements. The difference in the length of each timing bin results from differences in the sampling rate of each system.

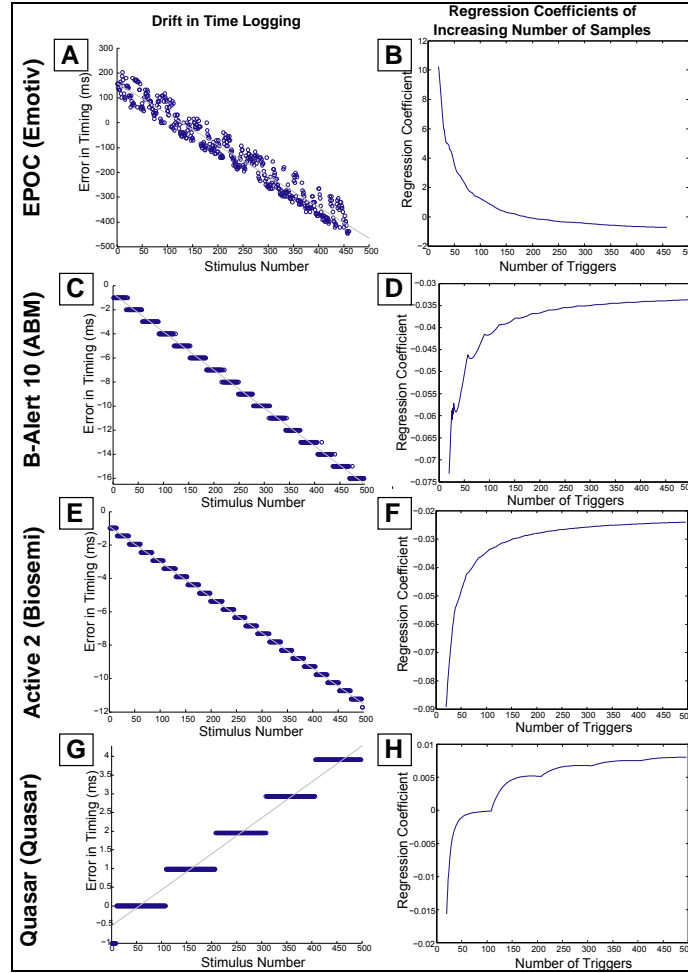


Figure 1. Drift in timing is shown for each system relative to the pulses sent from a computer running E-Prime software. The DAQ was not precise enough to measure the true time that each pulse was received. Rounding resulted in the step-wise features evident in E–H. Time drift with EPOC system is very large. A) The error between the trigger being logged by the DAQ and when it was sent is on the order of hundreds of milliseconds. B) In order to estimate the slope of the regression line, more than 300 calibration trials are necessary. C) Time drift with Biosemi’s ActiveTwo system. The error in time logging is relatively small, on the order of 10 milliseconds during this calibration session. D) About 250 trials are needed to accurately measure this drift. E) ABM’s B-Alert X10. Also on the order of 10 milliseconds, the drift in time logging is similar to that of Biosemi. F) Similar to Biosemi, ABM’s system also requires 250–300 trials to accurately represent the regression line. G) Quasar’s EEG system. Over the course of the calibration trials, Quasar’s system showed the least amount of drift in logging events, about 5 milliseconds total. H) This precision requires a large number of trials to compensate for the artificial binning of variance that results from the limited time resolution (about 300–350 trials).

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### 3. Conclusions and Recommendations

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Based on these results, we conclude that there is a large degree of variability of timing accuracy between commercially-oriented EEG acquisition systems. As we have shown here, a pre-determined number of pulses covering a pre-specified length of time is not appropriate for all systems. It should be noted that using this methodology with the Quasar headset, while several hundred pulses are necessary to achieve a statistically stable assessment of drift, the actual amount of change within each “step” is quite small—only 0.005% of the total time. According to the simulations in the previous report (Hairston, 2012),<sup>11</sup> this difference would be inconsequential for anything other than extremely long recording periods, suggesting that long calibration time may not be necessary if pragmatically difficult. However, in our test case, the measured direction of drift shifted from negative to positive after the initial 100 pulses, so at least this many calibration points would be a minimum.

Because at least 150 pulses, covering a span of 187.5 seconds, were necessary to appropriately calculate the drift factor for even the most ideal systems tested with the methods presented here, it is unlikely to be feasible to perform this calibration at the beginning of every data acquisition. Since many EEG experiments involve several data “runs”, this would require adding a notable amount of time to the duration of the experimental sessions. A few alternatives could be considered. For instance, it is common for an EEG participant to require considerable time for preparation and placement of electrodes before beginning the study; an experimenter could run a calibration test *during* this time period. Another option would be to send calibration pulses during the course of the EEG acquisition, or even use a log for the native event codes and use these for calibration later.

Moving forward, the timing drift should be measured for each system over a number of sessions in order to determine if the estimated value of drift is inherently stable for each system. If the drift is a stable, inherent property of the systems being used, then only a single calibration period would be required at the start of an experiment. If, however, the drift in time logging is not stable, then it must be assessed intermittently throughout the experimental session. This may involve presentation of calibration triggers before and after an experimental session, or even during the experiment if they can be presented in a way that does not influence the research participant.

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<sup>11</sup> Hairston, pg. 1.

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